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RESISTANT ALLOY WITH AN AlZnMg BASE, PART II

By

W. Rosenkranz

Translated from
Aluminium,
39, No. 12, 741 - 752 (1963)

Redstone Scientific Information Center

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DEVELOPMENT OF A HIGH-STRENGTH STRESS-CORROSION-RESISTANT ALLOY
WITH AN AlZnMg BASE

Part II: Influence of Chemical Composition on Artificial Age-Hardening
and Stress Corrosion of High-Strength AlZnMgCu Alloys

by

W. Rosenkranz, Meinerzhagen

Aluminium, Vol 39 (1963), No 12,
pp 741-752

The experimental results described in Part I of this report (Aluminium Vol 39 (1963), No 5, pp 290-297, and No 10, pp 630-637) demonstrated that it would be necessary to overcome the stress corrosion in high-strength alloys of the AlZnMgCu type also in the critical vertical direction of large extruded bars. It was found that the "chromb effect" in the aforementioned direction, which is generally considered to be very favorable, may be superposed or even made ineffective by the presence of lines of undissolved intermetallic phases. The question as to whether in this connection the aluminide of iron, chromium and manganese, or a copper-containing phase were particularly harmful could not yet be answered. Worthy of note was the very good behavior of alloys of the W-3435 type, in which the usual copper additive was wholly or partially replaced by silver. By using age-hardening temperatures of above 140°C, the stress corrosion would be eliminated in this kind of alloys also in the vertical direction.

These results were the starting point of a new experimental series with seven different alloys, having the chemical compositions shown in Table 18. They were supposed to give an answer to the following questions:

1. Influence of chemical composition on course of age hardening;
2. Static strength in the longitudinal and vertical direction;
3. Stress-corrosion behavior in the vertical direction; and
4. General stress-corrosion behavior in the weathering test, of T-section samples which have been bent (i.e., subjected to strong plastic deformation).

Using alloy A2, and according to the studies of Strawbridge, Hume-Rothery and Little [17] mentioned in Part I of this report, we attempted to bring the largest possible amount of copper into solution by raising the Zn content at the upper tolerance limit of alloy W 3435, as well as by reduction of the Mg content at the lower tolerance limit of the same alloy. The same objective was carried out with alloy A1; however, in this case, a part of the Cu was replaced with silver. The influence of strong lines of an insoluble iron-containing phase was to be determined by means of samples of alloy A3. Alloy A4 corresponds approximately to the prescription for W 3435. In the case of alloys A5 to A7 we have to do with alloys of type W 3425 with low iron- and manganese contents. A5 exhibits a normal Cu content, A6 an increased Cu content, while in the case of A7 an additional silver component is provided.

The alloys described were again present in the form of chill-cast blocks having diameters of 300 and 125 mm. To achieve different proportions of dissolved and undissolved copper in the final state, the chemical composition was varied, and in addition the casting was subjected to different annealing operations prior to extrusion. The blocks used in the study were subjected to one of the following preliminary treatments: a) no preliminary annealing; b) 30 hours at 440°C; c) 16 hours at 460°C followed by 14 hours at 480°C. The 300-mm blocks were extruded, under conditions already used in earlier studies, to large flat rods 200 x 85 mm, and the 125-mm blocks to T-sections or round bars of 15 mm diameter.

1. Influence of Chemical Composition on Course of Age Hardening

In the case of experiments with the above-mentioned 15-mm round bars (block homogenizing at 460-480°C), a uniform solution treatment at 465° in a salt bath for 15 minutes was employed; all samples were quenched in water at 60°, thus at a temperature which is possible under plant-operation conditions without any risk of causing lower strength in certain semi-finished products. The duration of storage at room temperature between quenching of the samples and the start of age-hardening was 1.5 hours to 61 days. The age hardening proper was carried out in liquid baths at 100, 120, 140, 160 and 180°C. The result of these experiments for alloys A1, A2, A5 and A7 are contained in Figs 16 to 19.

These data demonstrate the well-known fact that the tensile strength and the elastic limit become lower as the age-hardening temperature increases, while the strain at failure increases a little. The overaging, i.e., the lowering of tensile strength and elastic limit, occurs earlier the higher the age-hardening temperature. In addition to these normal facts the data further reveal that the magnitude of age-hardening in the case of the two lower temperatures, 100 and 120°, in the four alloys represented is either independent of the room temperature, or is dependent on it only to a very subordinate extent. At higher age-hardening temperatures (140-180°C), however, there exists -- as shown in the figures for the two Ag-free alloys A2 and A5 -- a considerable region of dispersion of the values of elastic limit and tensile strength. In general one may say at first that the values

of the lower limit of this spread are attained in the case of age hardening following immediately after quenching, and the upper limit in the case of age hardening after storing at room temperature for 61 days. By comparing Fig. 17 and 18 with Figs 16 and 19 it is possible to ascertain a very marked effect of the silver addition. This effect consists in the fact that the known spread found only in copper-containing alloys A2 and A5 (also A3, A4 and A6) which is a consequence of different periods of storing at room temperature, disappears at high age-hardening temperatures.

Table 18. Chemical Composition of the Alloys Investigated, in Percent.

Legierungs- bezeichnung	Cu	Ag	Fe	Mg	Mn	S	Zn	Cr	Ti
A 1	1.24	0.42	0.14	2.11	0.03	0.08	5.92	0.22	0.055
A 2	1.80	—	0.17	2.15	0.03	0.10	5.78	0.25	0.05
A 3	1.50	—	0.80	2.42	0.01	0.10	5.60	0.26	0.05
A 4	1.35	—	0.12	2.38	0.02	0.09	5.75	0.22	0.065
A 5	0.82	—	0.11	3.46	0.02	0.07	4.78	0.21	0.055
A 6	1.43	—	0.11	3.40	0.02	0.07	4.66	0.21	0.065
A 7	0.61	0.45	0.16	3.64	0.02	0.08	4.70	0.21	0.07

Rest Aluminium

1) Designation of Alloy 2) Rest Aluminum.

In Figs 20 to 23 the age-hardening curves for 160°C (see Figs. 16 to 19) are again drawn individually in order to show that quite marked differences in the values come about even by adhering to a given duration of storing at room temperature -- above all in the region of the age-hardening times used in actual practice, up to 10 hours, whose cause lies in an age-hardening mechanism present in these alloys which is not yet fully understood. As can be seen from Figs. 20 and 23, these differences, too, are decreased to a practically insignificant level by an addition of silver.

A further evaluation of the experiments involved the lowering of the maximum tensile-strength- and elastic-limit values in the case of rising age-hardening temperatures. According to the investigation of I.J. Palnear [6] in which, in accordance with the presentation made in the work cited, the Ag-free and Ag-containing samples to be tested were age-hardened immediately after quenching, one of the advantages of the addition of Ag is in the reduction of the decrease of strength in the case of high age-hardening temperatures which have been found to be very favorable for stress-corrosion behavior. As is shown by the practical evaluation of the experiments in Figs. 24a and 24b, this effect of the Ag addition is very great in the case of age hardening begun immediately after quenching; as the length of the intermediate storage at room temperature increases it becomes smaller -- the extent of decrease varying with the different alloys --, so that in the case of 61 days' storage there are no large differences with respect to the Ag-free alloys. It is worth noting that this equalisation of the strength values takes place in the following manner: They are displaced by the Ag addition also in the case of an immediate age hardening to a high value which in the case of

Ag-free alloys can be attained only upon age hardening after long periods of preliminary storage at room temperature. The described effects of the Ag addition which cannot as yet be satisfactorily explained, are of considerable practical importance, since they permit age-hardening at high temperatures to any desired length of time after quenching without thereby causing any marked dispersions and decreases of the strength values attained.

As was shown by comparative experiments with the Ag-free alloy A5 and Ag-containing alloy A7, the Ag addition eliminates the influence of storage at room temperature on the strength properties attainable at high age-hardening temperatures also in the case of a recrystallized structure brought about through strong drawing of the rods prior to solution treatment.

These same experiments enable one to make another, apparently very important observation, namely that in the presence of the press effect, high age-hardening temperatures cause a considerably greater contraction of the tensile-strength specimens than lower temperatures. Table 19 contains the strength properties including the measured reduction of area at break, taken from the age-hardening curves; in principle these properties are of the same order of magnitude for all alloys tested.

In addition to the effects of the elimination of the press effect in drawn rods which consist, as is well known, in a decrease of strength and elastic limit as well as an increase in strain at break and reduction of area, one can derive from the above data the following:

a) The reduction in area at break, which may be considered a measure of the deformation ability of a material [16] remains more or less constant in the case of samples which were only stored at room temperature and those which were age-hardened at 100° (valid up to about 125°), although at 100° the elastic limit and strength rise considerably. In reality, however, in the presence of the press effect to which particular attention should be paid, no area reduction in the proper sense of the term takes place, only a cross-section reduction caused by a proportional expansion.

b) The reduction of cross section, linked with a very genuine reduction of the area at break, is increased more than twofold in the presence of the press effect by increasing the age-hardening temperature to 160°C .

c) An increase of area reduction at break of about the same order of magnitude is achieved also by a full or partial elimination of the press effect.

d) In the absence of the press effect the area reduction at break, caused by age hardening at 160°C , is even further increased when compared with 100°C .

e) The view that the elastic limit is a measure of the brittleness of a material is only valid when no reduction of area at failure is present. When one considers the so-called "true stress," that is, when one relates

the load present in a tensile-strength experiment to the individual sample cross section, then the elastic limit calculated under these conditions is more favorable at 160°C than at 100°C, particularly when the press effect is present.

f) The lowering of the elastic limit at 160°C vs 100°C takes place in this case only in the Ag-free alloy, as was already described above, and only in the presence of the press effect, while in the case of a recrystallization texture no lowering of the elastic limit values is recorded.

The above observations point to the fact that the age-hardening processes occurring at temperatures between room temperature and about 125°C are dependent on the direction, that is, that in the presence of a press effect structure they take place to a greater extent in the longitudinal- than in the transverse direction.

Above the mentioned temperature limit another direction-independent age-hardening mechanism sets in, one that has a marked structural difference for consequence, as was described in Part I of this report; it also leads to a notably great increase of the area reduction at break, that is, a higher plasticity of the material. It is certain that this favorable effect of the high age-hardening temperature, which is to be discussed in greater detail after the conclusion of a series of experiments still in progress, is identical with experimental results described by H. Richter and G. Wassermann [18] for AlCuMg alloys. It was to be assumed that the greater plasticity achieved through high artificial age-hardening temperatures would play an important role with reference to the stress-corrosion behavior of the material in question.

2. Stress-Corrosion Experiments with Forked Samples of Extruded Flat 200x85 mm Rods in 0.01 N HCl Solution

Since the stress-corrosion behavior is most unfavorable in the vertical direction, the investigations described below were limited to forked samples taken in this direction, according to Figs 7 and 8 of Part I of this report, from the nuclear and rim structures of the rods. The heat treatment was likewise carried out according to the method described in

[Captions to Figs. 16 through 19 (See following pages); Key refers to all Figures.

Fig.16. Effect of Storage at Room Temperature on the Age Hardening of Ag-Containing Alloy A1 at Age-Hardening Temperatures of 100, 120, 140, 160, 180°C

Fig.17. Effect of Storage at Room Temperature on the Age Hardening of Ag-Free Alloy A2 at Age-Hardening Temperatures of 100, 120, 140, 160, 180°C.

Fig.18. Effect of Storage at Room Temperature on the Age Hardening of Ag-Free Alloy A5 at Age-Hardening Temperatures of 100, 120, 140, 160, 180°C.

Fig.19. Effect of Storage at Room Temperature on the Age Hardening of Ag-Containing Alloy A7 at Age-Hardening Temperatures of 100, 120, 140, 160, 180°C.
Key: 1) Age-Hardening Temperature; 2) Length of Storage at Room Temperature; 3) Hardness; 4) Time in Hours; Std = Hours; Tg = Days.]

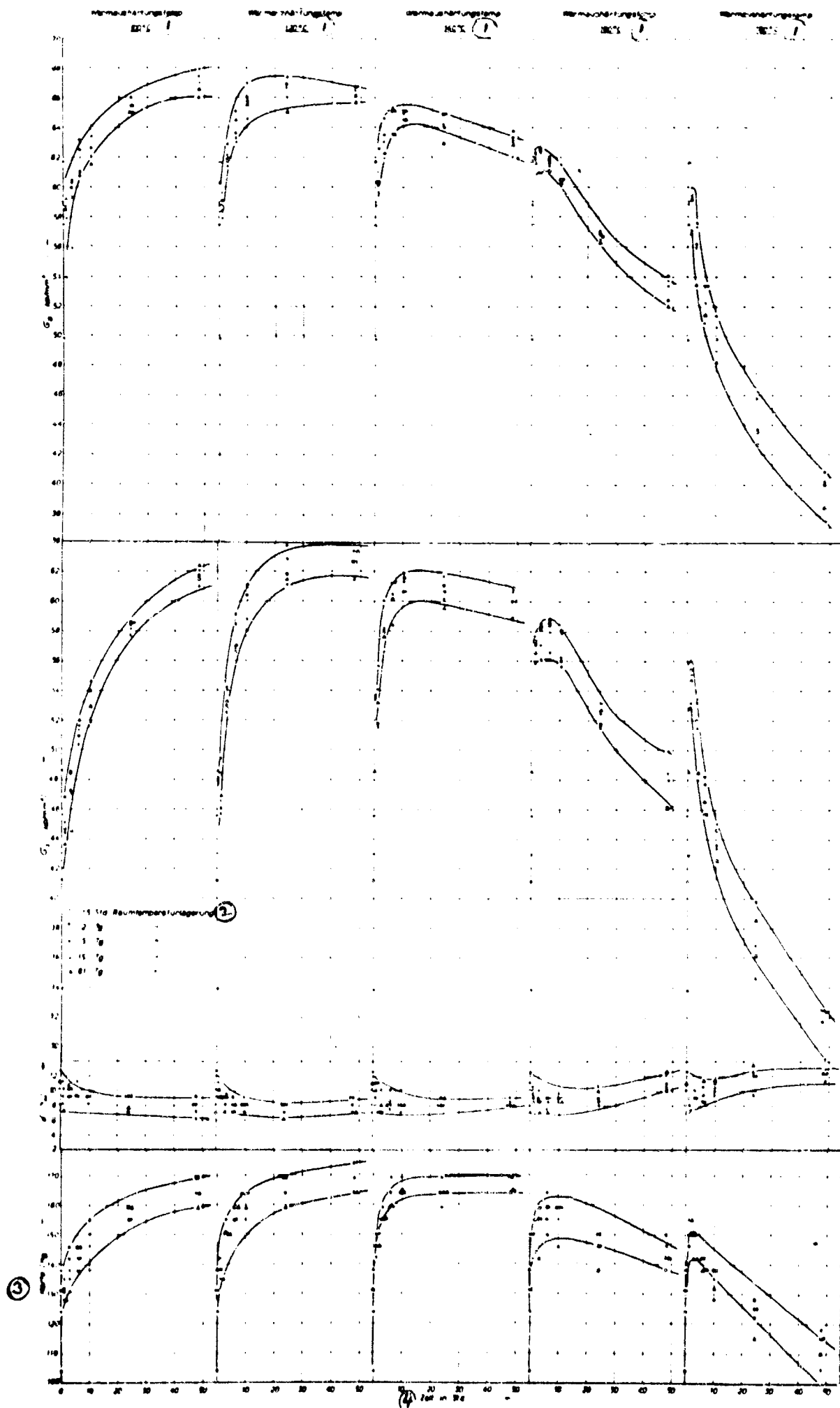


Fig.16

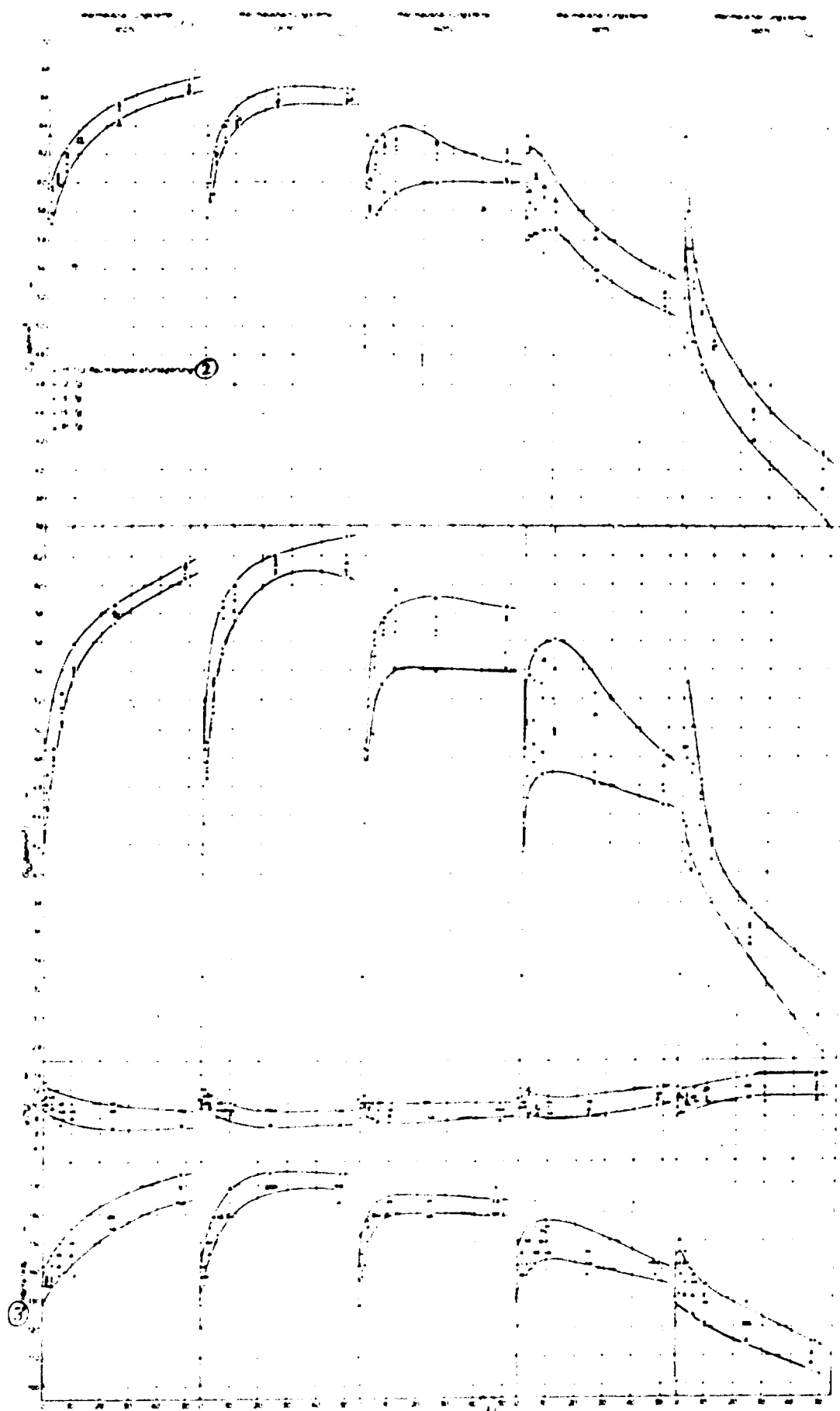


Fig.17

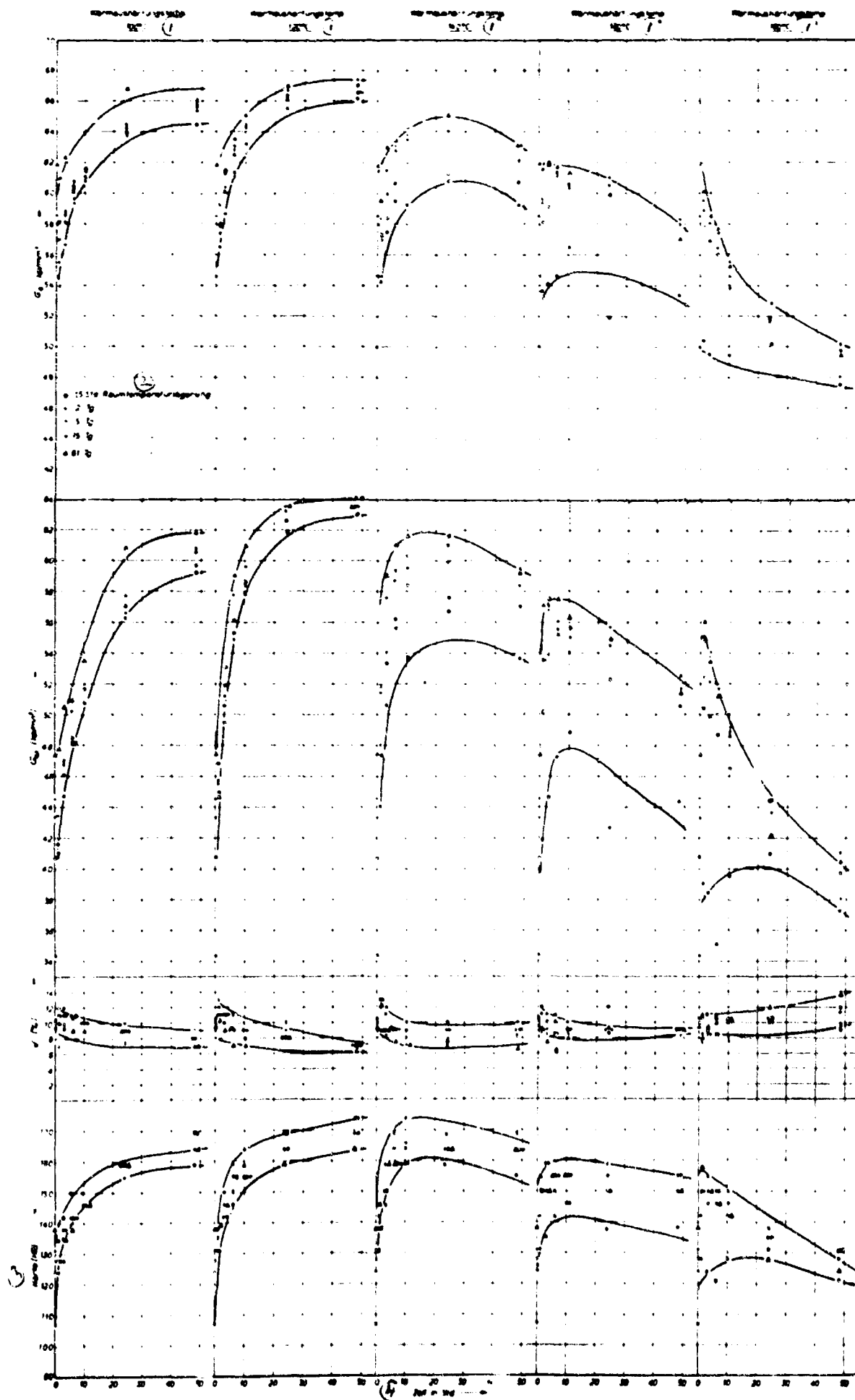


Fig.18

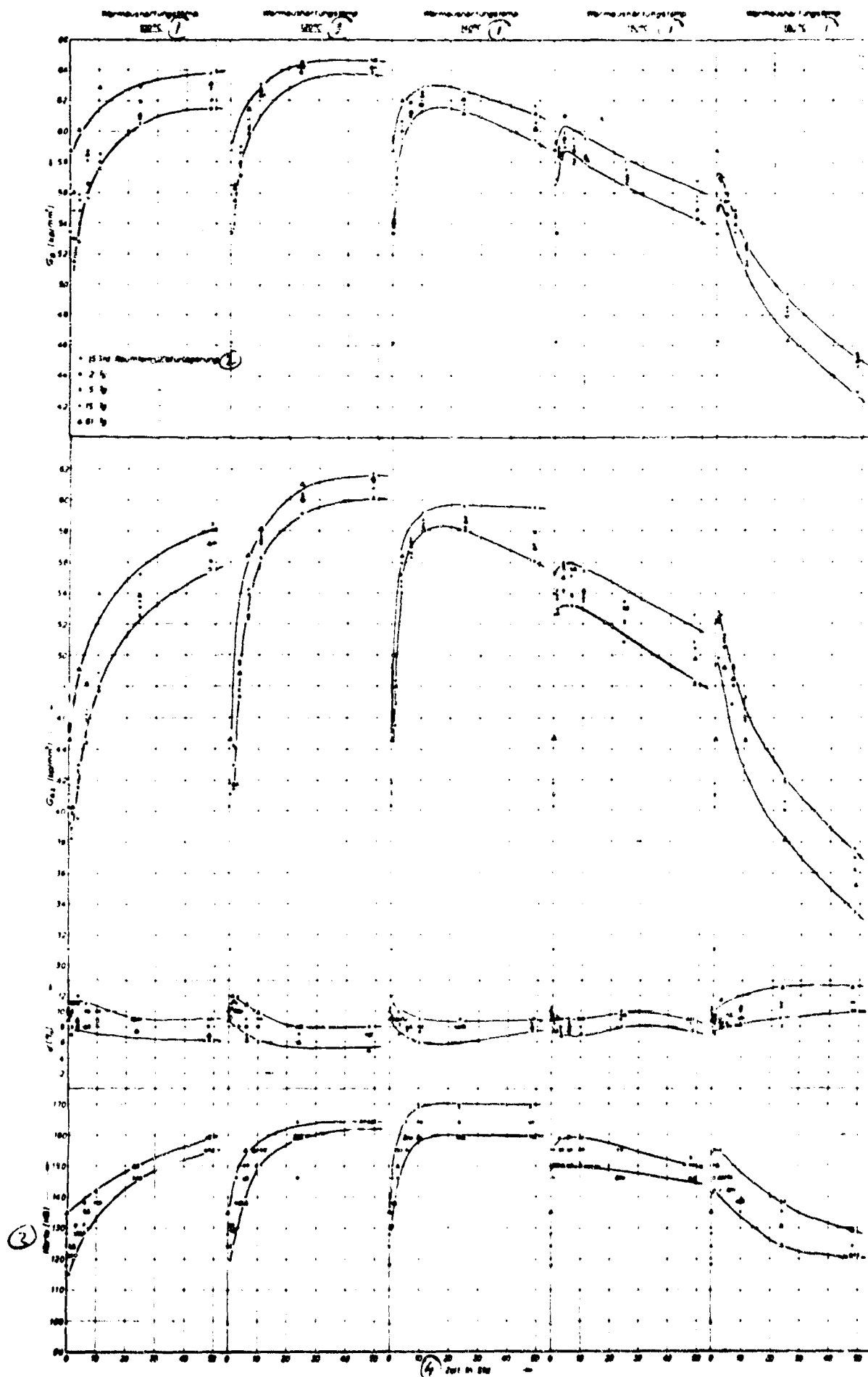


Fig. 19

part I of this report. The solution treatment lasted 15 minutes at 465°C in the salt bath; the quenching water had a uniform temperature of 60°C; after 10-14 days' storing at room temperature the samples were age-hardened in liquid baths at 120° and 160°C. In establishing the duration of age-hardening it was attempted, on the basis of suitable preliminary experiments, to attain, as much as possible, equal strength properties in the longitudinal direction of the nuclear structure. This attempt has been thoroughly successful, as shown by the graphs of Figs 25a and 26a, which include, in addition to the longitudinal values, also the values for the vertical direction, investigated for stress corrosion. Only alloy A7 gives somewhat lower strengths at 120 and 160°C, as was assumed already from the above-mentioned results of the preliminary experiments; the values of alloy A2 compared with the Ag-containing alloy A1 are a little lower only at 160°C, for reasons which have been discussed above.

Table 20 below contains the age-hardening times employed with the different pretreated samples. The average life durations of 5 forked samples are to be taken from Figs. 25b and 26b, for 120 and 160°C, respectively.

Table 19. Strength Values of Pressed and Drawn Rods of Alloys A5 and A7

Age-Hardening: a) 20 days cold-hardened; b) 20 days cold-hardened, 48 hrs at 100°C; c) 20 days cold-hardened; 6 hours at 160°C.

Legierung	Verformungs- zustand	Alterungs- zustand	Zug- festigkeit kp/mm ²	Streck- grenze kp/mm ²	Bruch- dehnung %	Ein- schrän- kung %
				⑩	⑤	⑥
A 5	gepreßt	kalt	55.5	41.5	11.5	17
		100°C	66.5	59.5	9.0	16
		160°C	60.5	56.0	11.0	36
	gezogen	kalt	49.8	31.2	24.0	31
		100°C	52.5	45.0	18.0	35
		160°C	54.0	48.2	15.5	48
A 7	gepreßt	kalt	54.2	39.0	12.0	17
		100°C	62.0	54.9	9.0	16
		160°C	59.6	54.5	11.0	35
	gezogen	kalt	47.5	30.2	24.0	32
		100°C	55.0	45.0	17.0	32
		160°C	52.0	47.5	14.5	46

1) Alloy 2) State of Deformation 3) Age-Hardening State 4) Tensile Strength 5) Elongation at Break 6) Reduction of Area at Break 7) Pressed 8) Drawn 9) Cold 10) Elastic Limit

The following results were obtained:

a) The static strength values play only a quite subordinate role in the investigated alloy group, compared with the differences in chemical

composition and texture. The attempt to establish a life duration vs. tensile strength-, or a life-duration vs elastic limit curve fails because of the overwhelming influence of the other factors. The same holds true for the elongation at failure which is reduced in the vertical direction in alloy A3 by strong FeAl₃ bands, and especially in the case of alloy A6 by residues of an undissolved Cu-containing phase; while the FeAl₃ bands produce no noteworthy lowering of the life expectancy which is particularly great in the case of the presence of residues of the Cu-containing phase.

Table 20. Data Regarding the Type of Age Hardening of the Different Pre-Treated Samples

Legierung	bei 120°C		bei 160°C	
	in h	in %	in h	in %
A 1	8		8	
A 2	8			
A 3	5		5	
A 4	5		5	
A 5	8		8	
A 6	8		8	
A 7	8		8	

1) Alloy 2) at 120°C, hours 3) at 160°C, hours.

b) It is possible to attain a practically complete elimination of the susceptibility to stress corrosion in alloys A1 to A4 -- particularly in the critical vertical direction of the nuclear and rim temperatures -- by age hardening at 160°C, when the strength values are about the same.

c) The markedly favorable effect of a combined Cu-Ag addition is noted also in this case, as was observed in the results described in Part I of this report. At any event it is noticeable only in those alloys or states which are not characterized by long life duration for other reasons. In all these cases it can be seen that the two CuAg-containing alloys A1 and A7 give the most favorable results. By comparing the two alloys A1 and A2, the slight drop in strength at 160° in the longitudinal and vertical direction caused by the Ag addition is again noticed, as has already been described in another connection.

d) Alloys A1 to A4, exhibiting a higher Zn- resp. Cu content but a lower Mg content, behave better in a vertical-direction test than alloys A5 to A7 with a lower Zn content but a higher Mg content. Particularly unfavorable is alloy A6 in which no solubility exists for the relatively high proportion of copper, due to the high Mg content. The tendency that the stress-corrosion behavior is improved by an as high proportion of soluble copper as possible, but that residues of undissolved primary Cu phase have a very unfavorable effect, is observed upon comparing the different alloys, in agreement with the above-mentioned studies [17] on the solubility of Cu in AlZnMg alloys; the same holds true in this regard for the two preliminary annealing temperatures of 440° and 480°C, used for the blocks.

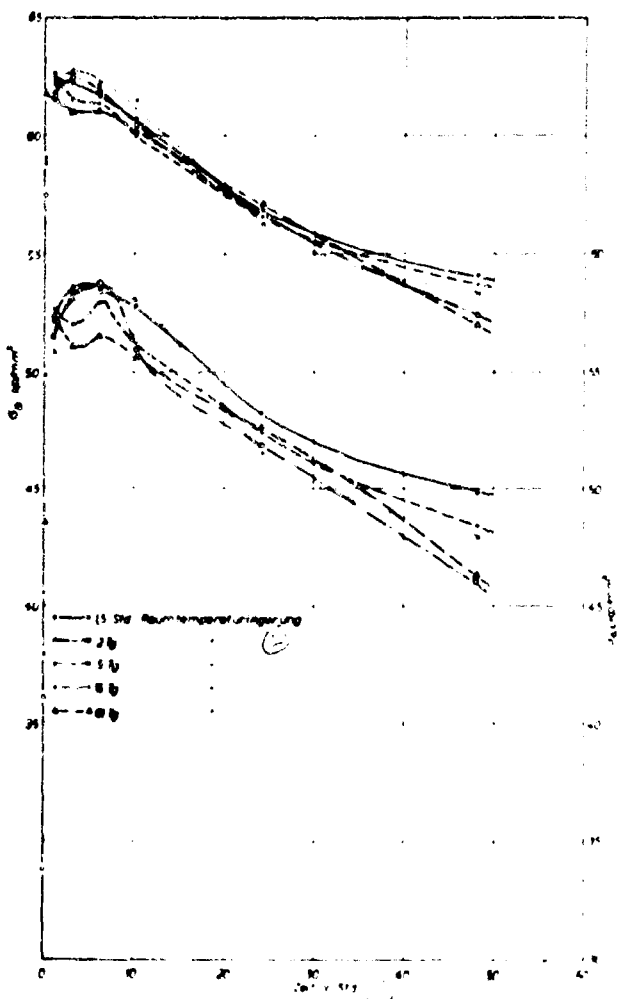


Fig. 20

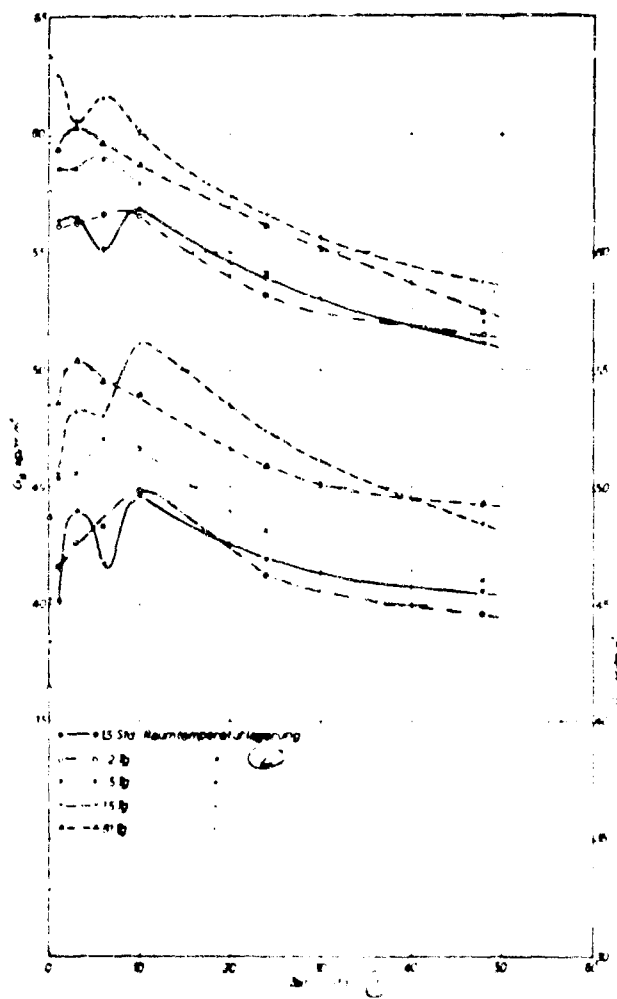


Fig. 21

Figs. 20 and 21: Effect of Storing at Room Temperature on the Course of Age Hardening of (Fig. 20) Silver-Containing Alloy A1 (Fig 21) Silver-Free Alloy A2; Age-Hardening Temperature in both cases 160°C . 1) Time in Hours 2) Storing at Room Temperature; Std= Hours; Tg = Days.

e) It was found that the stress-corrosion behavior is only slightly impaired by the heavy FeAl_3 bands present in alloy A3.

3. Stress-Corrosion Experiments with Bent T-Sections in Weathering

The extruded blocks of 125 mm diameter from alloys A1 through A7 used in these experiments, were heated prior to extrusion as follows:

- No preliminary annealing.
- 30 hours at 440°C .
- 16 hours at 460°C , 14 hours at 480°C .

They were pressed into T-sections under the conditions described in Part I of this report, annealed for 15 minutes at 465°C in a salt bath, and quenched in water at 60° . The age-hardening was carried out at 120° and 160° following a period of 10 to 14 days at room temperature. In order

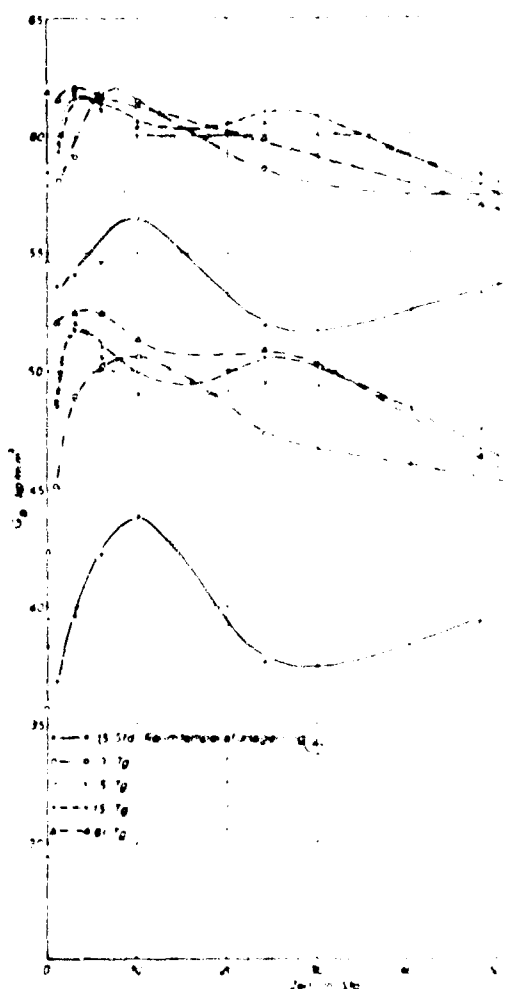


Fig. 22

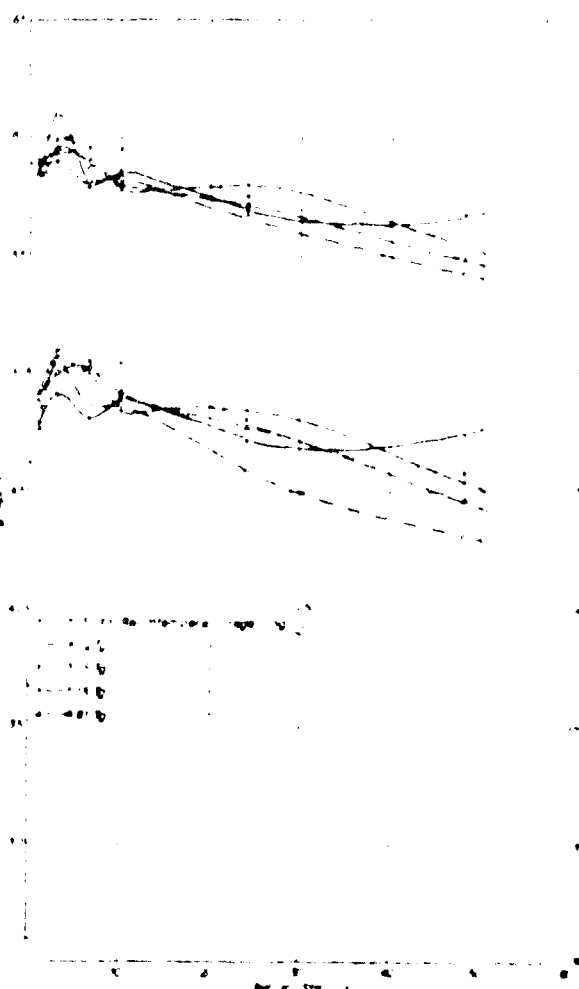
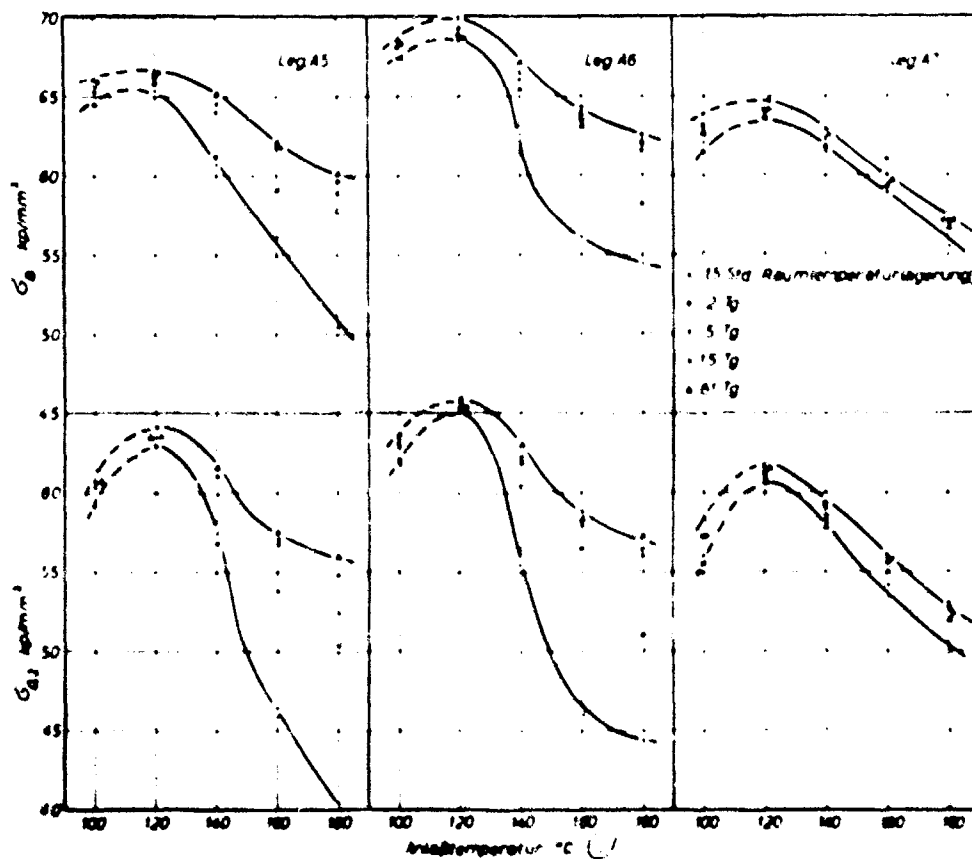
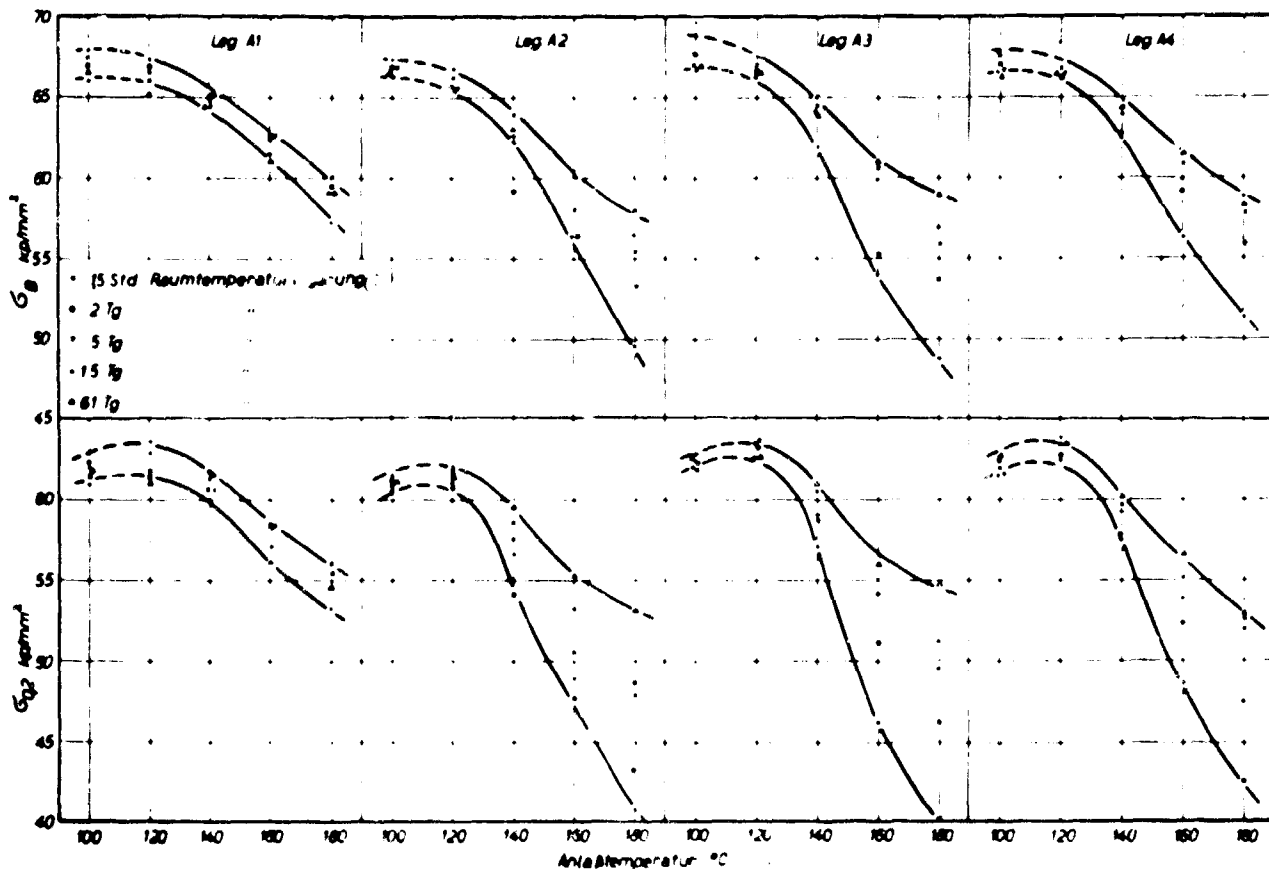


Fig. 23

Figs. 22 and 23: Effect of Storing at Room Temperature on the Course of Age Hardening of (Fig. 22) Silver-Free Alloy A5 (Fig. 23) Silver-Containing Alloy A7; Age-Hardening Temperature in both cases 160°C. 1) Time in Hours; 2) Storing at Room Temperature; Std = Hours; Tg = Days.

to achieve the same stresses in the stress-corrosion tests, the duration of age-hardening was again chosen in such a manner that the samples of the different alloys, and the states, were characterized by approximately identical strength properties. As shown by the graphs of Figs. 27 and 28, this aim was achieved to a great extent; in individual cases, however, no agreement of the values is possible due to reasons which will not be discussed here any further; this circumstance, however, plays a role also in this case, as in that of the experiments with forked samples just described. After age hardening the sections were bent by 8° around the wet, thus subjected to a strong plastic deformation, and exposed to the weathering test in this state; here we have to do with a very sharp stress-corrosion test which has already been described in great detail elsewhere [5].

[For caption to Figs. 24a and 24b on next page, see top of p 15.]



Figs. 24a and b

Figs. 24a and 24b: Effect of Storing at Room Temperature on the Age Hardening of Different Alloys of the AlZnMg Type. 1) Temperature of Tempering 2) Storing at Room Temperature Leg. = Alloy; Std. = Hours; Tg. = Days.

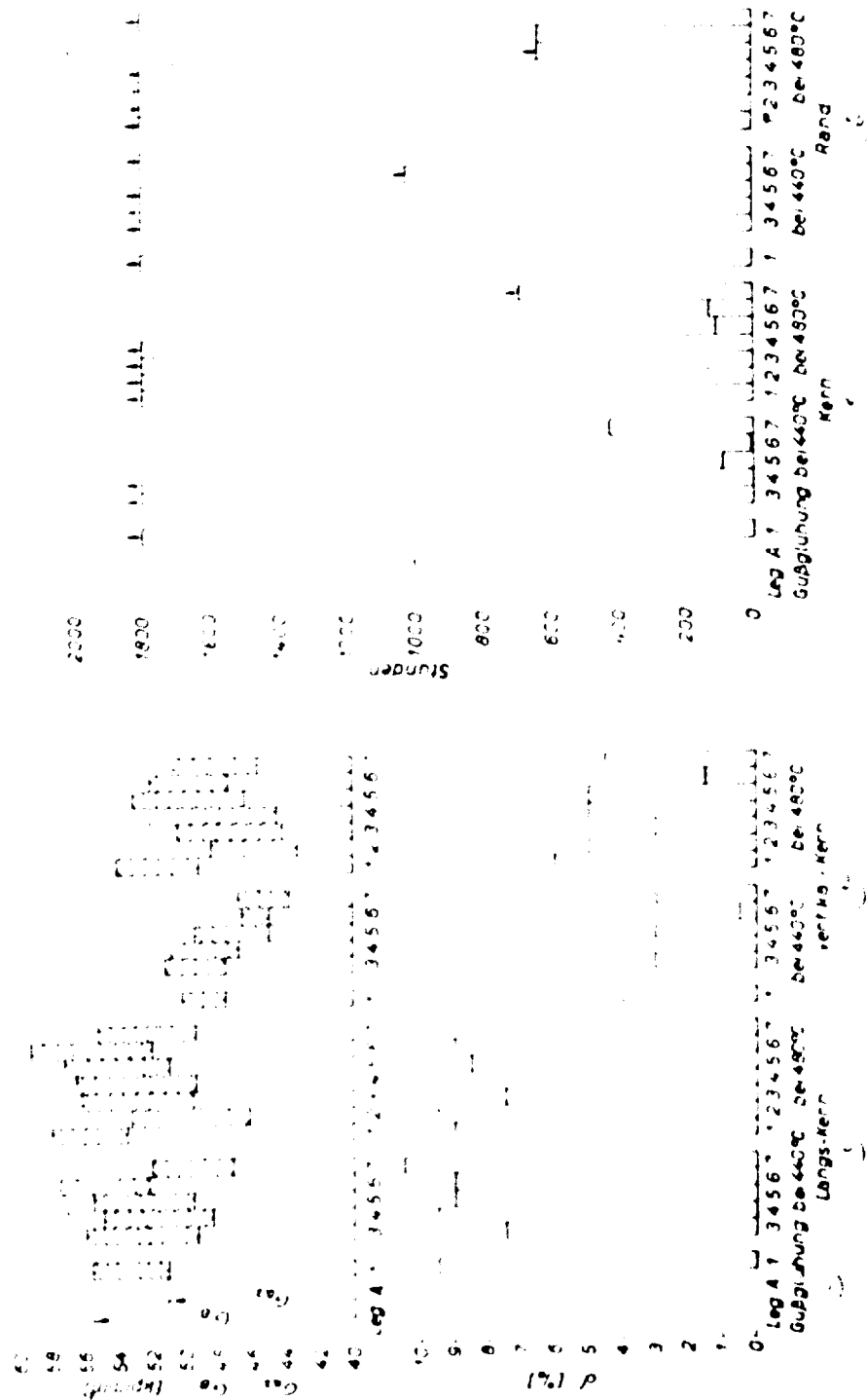
The average life duration of 5 samples is represented in the lower part of Figs 27 and 28. The experimental results obtained in the weathering test practically agrees with the results obtained with forked samples from large experimental flat rods. Here, too, we succeeded under the chosen conditions for a whole series of alloys resp. states, to eliminate the stress corrosion, above all after plastic deformation of the age-hardened state. Particularly great effects could be obtained by means of high age-hardening temperatures, with the combined addition of Cu and Al, as well as by avoiding a high Mg content which decreases the solubility of copper. By using the critical but heretofore quite usual age-hardening temperature of 120° the favorable effect of silver is clearly observable in the case of both alloys Al and A7. To be noted, in addition, is the fact that the sections from non-pre-annealed cast rods behave worse in the case of an age-hardening at 120° than those made of pre-annealed casting. This is to be attributed above all to the greater tendency of such sections during inductive heating to recrystallization during the solution treatment.

To conclude this second part of the report we would like to say a few words on the testing method employed in the experiments described. The forked sample permits the testing of a large number of alloys and states, particularly the dependence on direction in heat-deformed semi-finished products, using simple means. The disadvantage lately attributed to this test, to wit, that it does not allow the testing of a defined stress state, can be eliminated by the creation of nearly equal strength values to such a great extent that the load differences still occurring have a completely subordinate significance in comparison with other factors which have an influence on stress corrosion; the accuracy of this view is clearly expressed by the experimental results communicated. The same can be said also about the testing of bent I-sections in weathering.

For proof of the correctness of the view represented we would like to communicate a few experimental results obtained in the weathering test with a large number of samples with a definite stress. Here we have to do with the so-called ring samples taken from thick-walled, extruded pipes: such a sample is shown in Fig. 29. It has been used for quite some time for production control. The results of this sample fully agree with those described in the previous report. In the case of the first experiment to be described here the pipes, 112×10 mm, were of an alloy of type W-3425. After solution treatment at 450°C they were quenched in water and then age-hardened, partly for 12 hours at 120°C and partly for 4 hours at 145°C . From the different pressed pipes present in the two different states ten samples each were taken; on the ring sample age-



Figs 25a and 25b: Strength Values in the Longitudinal and Vertical Direction of Flat Bars 200 x 85 mm. Alloys A1 to A7: Age-Hardening Temperature 120°C. (Fig. 25b: Average of 5 Tests.) 1) Hours 2) Casting Annealing at 3) Lengthwise 4) Vertical 5) Nucleus 6) Rdm 7) Alloy



Figs 26a and 26b: Strength Values in the Longitudinal and Vertical Direction of Flat Bars 200 x 85 mm, Alloys A1 to A7; Age-Hardening temperature 160°C. (Fig. 26b: Average of 5 Tests). For Key, see Figs. 25a and 25b.

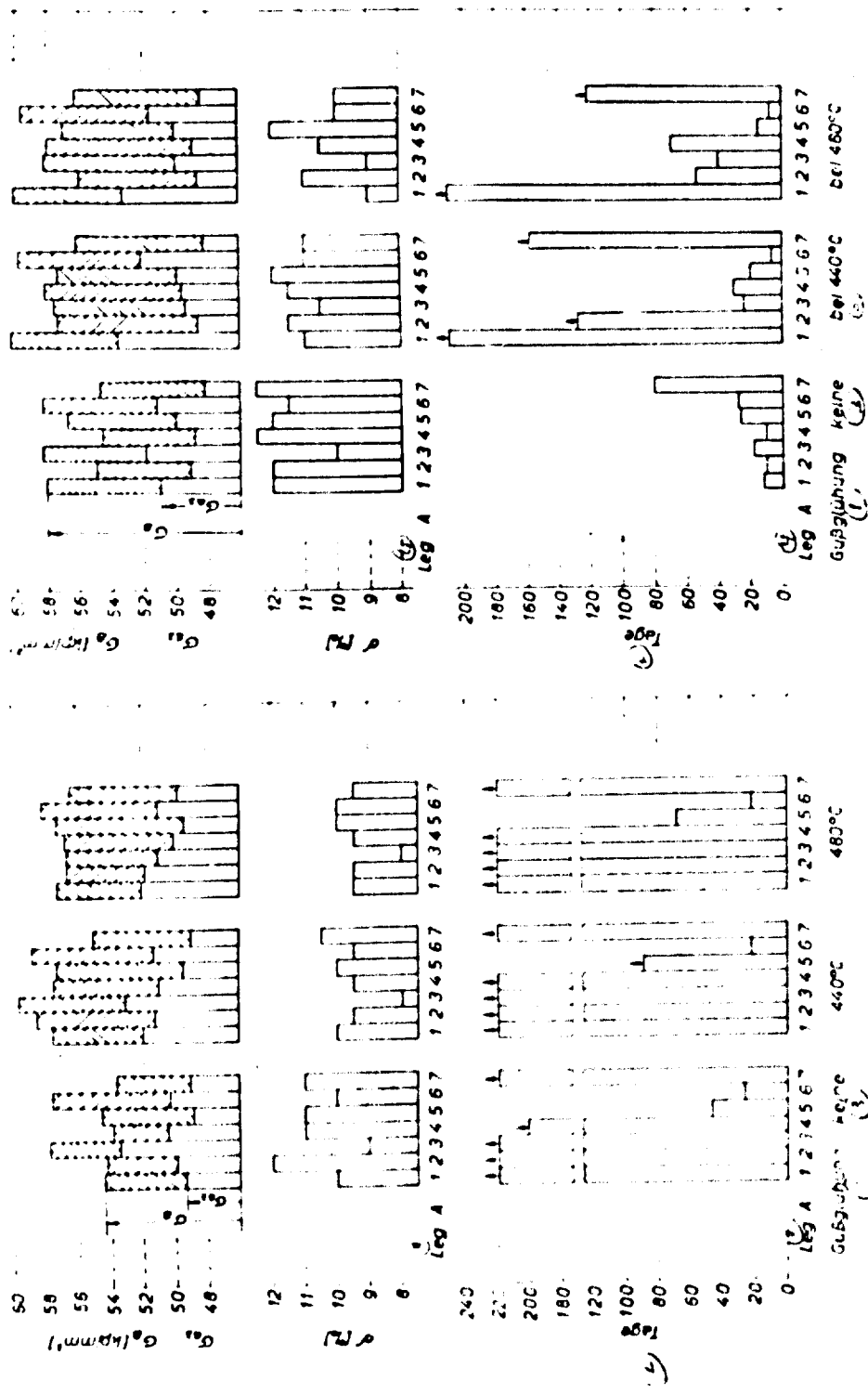


Fig.27: Strength Values and Life Durations of Bent T-Sections in Weathering; Age-Hardening Temperature 120°C. 1) Casting Annealing; 2) Days; 3) None; 4) Alloy

Fig.28. Strength Values and Life Durations of Bent T-Sections in Weathering; Age-Hardening Temperature 160°C. For Key, see Fig. 27. 5) At

hardened at 145°C we determined the load at which a plastic deformation set in, and then all samples were subjected in the same manner to a stress amounting to 8% of this load. The static strength values of the two sample groups in the longitudinal direction, and the life durations of the ring samples are summarized in Table 21.

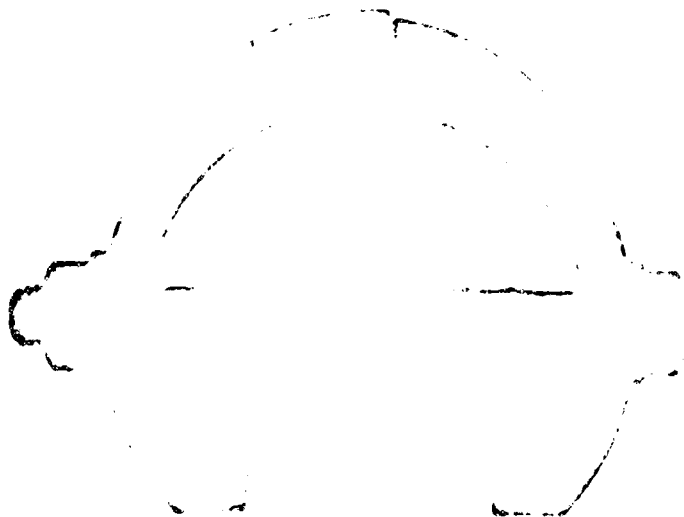


Fig.29. Ring Sample From a Thick-Walled Extruded Pipe

Again it can be seen from these results that the effect of high-age-hardening temperatures is very favorable. Group B does not exhibit any break after 1275 days, despite the fact that these samples were stressed with 80% of the elastic limit, while the stressing of the samples of Group A with an average life duration of 371 days consisted of only about 55% of the elastic limit. The described method of carrying out the experiment -- i.e., the same stressing of both groups of samples despite actually existing, different elastic-limit values -- was chosen for the reason that the construction engineer bases his calculations not on the attained or attainable values but the guaranteed values.

Table 21: Experimental Results with Ring Samples from W 3425, in Weathering

Gruppe	Warmaus- härtung	Festigkeitswerte in Langsrichtung			Bruch nach Tagen	Mittlere Lebens- dauer (t) in Tagen
		σ_B kp/mm ²	$\sigma_{0.2}$ kp/mm ²	σ_s kp/mm ²		
A	12 h 120°C	60.0	54.6	10	200 240 270	371
					300 360 420	
		59.4	54.4	10	480 480 480 480	
B	4 h 145°C	52.5	46.2	11	kein Bruch	1275
		51.2	46.4	11		

- 1) Group 2) Age-Hardening 3) Strength Values in Longitudinal Direction
 4) Break after Days 5) Average Life Duration in Days 6) No
 Break

In the same manner we used ring samples of pipes of the above-mentioned alloys Al, A2 and A5. The pipes made of alloy A5 exhibited, after age-hardening at 120°C, elastic-limit values of about 50 kp/mm²; those made of alloys Al and A2, after age-hardening at 170°C, about 45 kp/mm². After an experimental period of 270 days -- up to the time of writing -- about 60% of all samples of alloy A5, which had been stressed with 80% of the elastic limit of Al and A2, are broken, while in the samples of alloys Al and A2 no break has as yet occurred.

Summary

The experiments described in Parts I and II of this report, relating particularly to the stress-corrosion behavior of extruded sections of greater or lesser dimensions, made of high-strength AlZnMgCu alloys in an acid corrosion medium (0.01 N HCl) and in the atmosphere, have first led to the result that there exists in the "fine-grain zone" at the edge a considerably smaller dependence of the life duration of the sample on direction than in the "nuclear structures" stressed with the press effect. The durability of the fork samples in the very critical vertical direction was very small; as may be seen from Tables 9 through 11. The addition of chromium which otherwise has such a favorable effect on the stress-corrosion behavior has no noteworthy improving effect. It was found that residues of an undissolved Cu-containing phase cover up and nearly inactivate the "chromium effect" while FeAl₃ bands have a surprisingly small effect. By accurate adjustment of the Zn, Mg, and Cu components of the alloy as well as by means of homogenization of the casting which brings the copper present to complete solution the "chromium effect" may be made to exert its full activity also in the vertical direction of the nuclear structure; in these measures the magnitude of the magnesium content which has a particularly injurious effect on the solubility of Cu acquires a very great significance. A greater certainty is assured when a part of the copper is replaced with silver, since the solubility of silver is not reduced as strongly by magnesium as that of copper. By resorting to this type of measure the possibility is created for setting the magnesium content, which improves the static and dynamic properties of the alloy, to such a level that no deterioration in these properties sets in compared, e.g. with those of material W 3435.

Under the preconditions described above we may consider the problem of stress corrosion of alloys of the AlZnMg type, when using age-hardening temperature between 140°-170°C, as practically solved also for the critical vertical direction. Further, the intentional and unintentional plastic deformations in the age-hardened state, which have so far been rightly judged to be very critical, are also to be considered, on the basis of the suggestions made, as substantially less risky in their effects, as was shown by the experiments with bent T-sections.

In addition to the immediately favorable effect on the stress-corrosion behavior, produced by the addition of silver, the latter has two other advantages:

One consists in the fact that it markedly retards the lowering of the static strength values occurring with increasing age-hardening temperatures, when the usual periods of storage at room temperature are employed between quenching and age-hardening, and that in this indirect manner it contributes to the elimination of stress corrosion by making it possible to use higher age-hardening temperatures.

The second advantage of the addition of silver consists in the fact, important for the manufacturing process, that the influence of the duration of storing at room temperature on the values attainable through age hardening, present in silver-free AlZnMgCu alloys, are eliminated. This means that the hitherto customary periods of storage at room temperature may be abolished, and that dispersion effects brought about as a function of the length of age-hardening due to the not readily understandable overlapping of different age-hardening mechanisms, are also prevented.